INTRODUCTION

Capillary pumped loops (CPL's) are devices that are used to transfer heat from one location to another; specifically they transfer heat away from something. In low-gravity applications such as satellites (and possibly the International Space Station), CPL's may be used to transfer heat from electrical devices to space radiators. The transfer of heat is accomplished by evaporating off of one liquid surface at the hot side and condensing the vapor produced at another liquid surface at the cold side. Capillary action, that is, the phenomenon which causes paper towels to absorb spilled liquids, is used to "pump" the liquid back to the evaporating liquid surface (hot side) to complete the "loop."

The advantages of CPL's are that they require no power to operate and they can transfer heat over distances as large as 30 or more feet. Their reliance upon evaporation and condensation to transfer heat makes them much more economical in terms of weight than conventional heat transfer systems. The disadvantage of CPL's is that they have proven to be unreliable in space operations and the explanation for this reliability problem has been elusive.

The Capillary-Driven Heat Transfer (CHT) investigation was conceived to study the fundamental fluid physics phenomena thought to be responsible for the failure of CPL's in low-gravity operations. CHT will be conducted in the Microgravity Glovebox (MGBX) facility of the Shuttle Spacelab during the first Microgravity Science Laboratory (MSL–1) mission scheduled for April 1997.

SCIENCE OVERVIEW

The CHT Glovebox (GBX) investigation will study the dynamics associated with heating and cooling at the evaporating meniscus within a capillary-driven heat transfer device in a low-gravity environment. A generalized diagram of this type of device is shown in figure 1. A CPL transfers heat by evaporating fluid at one end (evaporator) of a fluid column, transferring the vapor through the loop to the other end of the column, and recondensing the fluid there (condenser). Capillary action drives the recondensed liquid back to the evaporator side.

The premise for the CHT research is based upon previous internal pressure measurements of CPL devices when unexpected system failure has been observed. In virtually all cases, substantial pressure oscillations have been observed. Previous research by Hallinan and Allen has shown that these pressure oscillations can be attributed to unstable evaporator menisci. Short-duration rapid evaporative flux increases have been observed. This rapidly evaporating liquid gives rise to significant vapor recoil stresses on the menisci present in the evaporator which causes the liquid to recede from the heated zone. Capillary and drag forces eventually dissipate the energy added to the liquid by the accelerating vapor. The liquid then attempts to rewet the now dry evaporator. Thermocapillary flows induced near the advancing contact line as the liquid attempts to rewet the hotter surface can inhibit the movement of the liquid. At high enough heat levels, the evaporator dries out and the system fails.

The scientific and technological significance of the CHT investigation has exciting implications for the use of capillary-driven heat transfer devices in microgravity. These devices offer the benefits of low weight, passive operation, and high heat transfer. However, such devices have performed unreliably in a space-based operation despite their successful performance in normal gravity. If the failure mechanism can be definitively identified, then appropriate design modifications can be envisioned to alleviate the failure mode, thereby making capillary-driven heat transfer devices a more viable option in space applications.

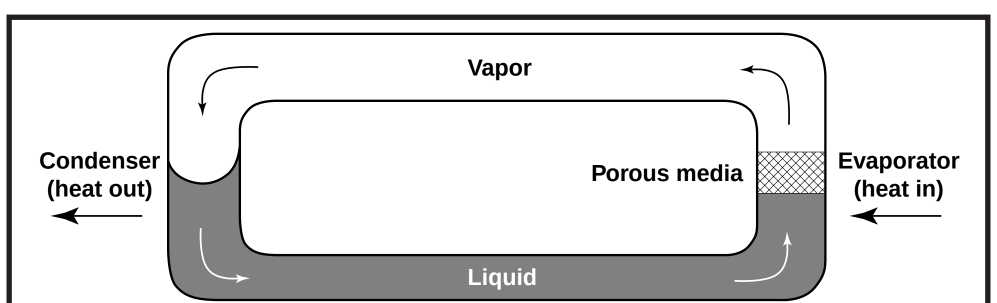

Figure 1.—Typical capillary pumped loop (CPL).

MISSION OBJECTIVES

The CHT investigation will result in an improved physical understanding of the mechanisms leading to the unstable operation of and failure of capillary-pumped heat transfer devices in low gravity. The following specific goals of the investigation that will be achieved by executing eight experiments are:

- To understand why capillary pumped heat transfer devices have failed in low gravity, and, in particular, to show that instabilities associated with the evaporating meniscus are responsible for the unreliable operation observed in practice
- To further demonstrate that the instabilities originating in the evaporator in low gravity are mainly associated with thermocapillary instabilities
- To observe how the evolution of the instabilities is manifested differently in low gravity in comparison to their evolution in Earth's gravity; the coupling between the condenser and evaporator sections of the CPL will be visualized for the first time
- To show that the formation and subsequent evolution of the aforementioned instabilities are dramatically affected by the 'direction' of heat input, that is, heat input from the liquid or vapor side of the meniscus
- To determine whether an unstable CPL system can be restabilized

HARDWARE DESCRIPTION

The CHT experimental hardware consists of two experiment modules that each contain a test loop (idealized CPL), a base unit for power conversion and back lighting; a display unit with 15 light emitting diodes (LED's) to display temperature, pressure, heater power, and time; a control unit to

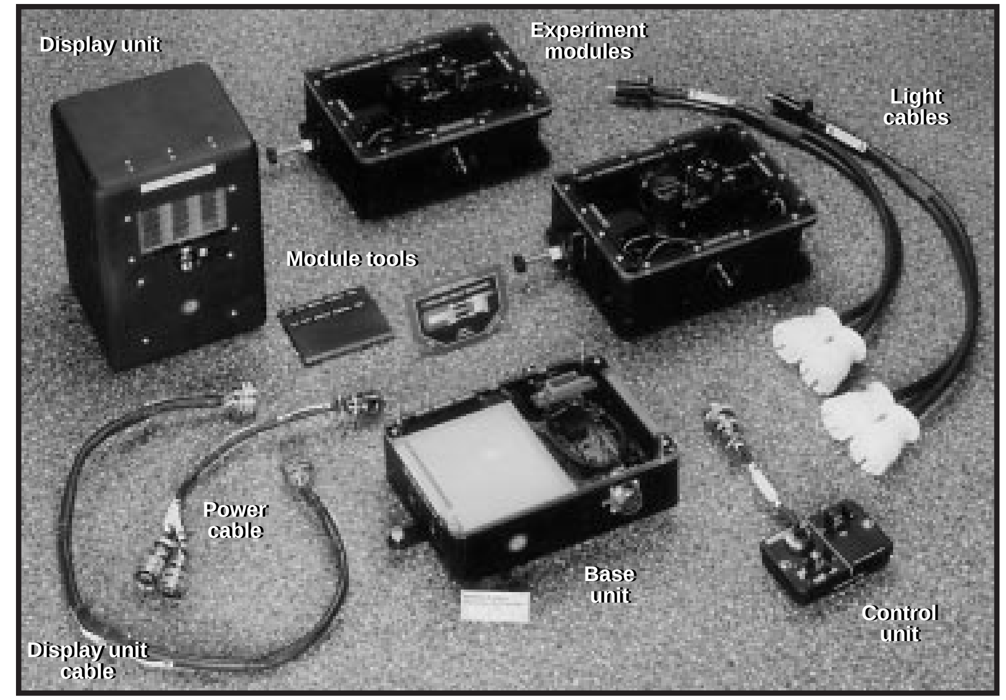

Figure 2.—Hardware components used in Capillary-Driven Heat Transfer (CHT) investigation.

select heaters and heater settings; and associated cables (fig. 2). Each experiment module contains an instrumented Pyrex test loop that is in a racetrack configuration. Experiment module 1 is shown in figure 3. Figure 4 is a schematic of the test loop. The only difference between the test loops is the inner diameter of the evaporator section. In experiment module 1 the inner diameter of the evaporator is 1 mm, while the inner diameter of the evaporator in experiment module 2 is 4 mm. The difference in the evaporator diameters between the test loops will provide a comparison of the loop behavior when the capillary "pumping" is different. (A smaller diameter tube size provides a greater capacity to move the liquid.) The condenser leg in both modules is 10-mm-diameter tubing. Within each loop is a three-way valve, referred to as the control valve. This valve is used to direct the test liquid, ethanol, from the glass syringe reservoir into the condenser leg and/or the evaporator leg of the test loop. The reservoir is a 10-cc syringe with a screw-type plunger.

As shown in figure 4, the loops are instrumented with two heaters that will provide heat input from the liquid or vapor side of the evaporator meniscus. The vapor-side heater (cone heater) is a Kanthol wire attached to the conical transition section of the evaporator in a serpentine fashion. The liquid-side heater (capillary heater) is a spiral-wound Kanthol wire attached to the capillary tubing approximately 10 mm from the cone heater. When the cone heater is used, the temperature gradient along the thin film region of the meniscus is cooler towards the liquid side. The capillary heater reverses this temperature gradient. Cooling of the condenser leg is accomplished by forced air convection at ambient temperature through the use of a small fan.

The test loops are also instrumented with a total of 11 thermocouples (Type T, 40 AWG). There are 7 thermocouples along the length of the evaporator leg and 4 thermocouples along the length of the condenser leg. The thermocouples are located 0.010 in. from the inside wall. This proximity to the inside wall coupled with the fine gauge of the thermocouple wire will provide a quick response to wall temperature changes. Heater temperature ranges are expected to range from ambient to 300 °C. An additional thermocouple and a pressure transducer are connected to the vapor leg.

The CHT flight hardware will utilize the GBX facility and associated resources in Spacelab during the MSL–1 mission. A video record of the test loop activities and the digital displays associated with the CHT experiments will be recorded with one of the Spacelab camcorders and GBX cameras, respectively. When feasible, the video signals will be downlinked in real time to the CHT team which will monitor experiment operations from the Payload Operations Control Center in Huntsville, Alabama.

Figure 3.—Experiment module 1 used in Capillary-Driven Heat Transfer (CHT) investigation.

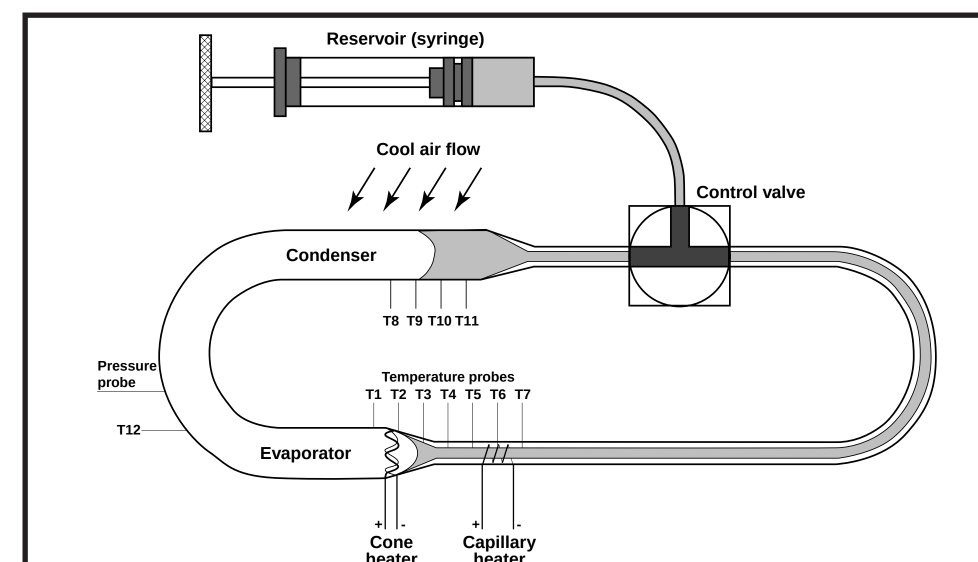

Figure 4.—Schematic of CHT Experiment test loop.

OPERATIONAL SEQUENCE

One of the crew members will unstow the CHT hardware from two Spacelab lockers and install it in the MGBX work area. The Spacelab camcorder and a color video camera will be positioned to view the experiment module and display unit. Appropriate settings will be made and the focus set.

Eight different CHT experiments will be performed during the course of the mission. Prior to each experiment, initial conditions will be set; this includes selecting a module, filling the test loop to appropriate levels, selecting a heater, and so forth. During the execution of the experiments, the evaporator section will be heated either from the liquid or vapor side of the meniscus. Heat input will be gradually increased to create the unstable systems, and decreases in heat will be used to restabilize the test loop. During the experiments, the evaporator and condenser wall temperatures, vapor temperature, and pressure data will be monitored and recorded. Also, the behavior of the liquid surfaces will be monitored and recorded for further analysis. The data will be used to evaluate conditions and properties that affect the system operations. The astronaut's observations, interaction, and operation of CHT are critical to experiment success.

POSTFLIGHT DATA ANALYSIS

The test cell wall temperature and bulk fluid temperature data in the vicinity of both the evaporating and condensing menisci will be used for the following: (1) evaluation of fluid thermophysical properties in the interfacial region, (2) bulk fluid property determination, and (3) determination of the wall temperature gradient in the vicinity of both the evaporating and condensing menisci. Knowledge of the temperature gradients will allow for the determination of the near-contact-line thermocapillary stress and, therefore, the Marangoni number. The thermal conditions at the onset of an instability will be observed. The wall temperature data near the contact lines will also be used to evaluate the thermal history after the evaporator meniscus destabilizes.

The pressure data will be useful for establishing bulk vapor properties (in conjunction with bulk vapor temperature data). It will be also useful in evaluating the thermal and liquid resupply frequencies by observing the vapor pressure oscillations.

The video data will be used to determine how the measured thermocapillary stresses affect the macroscopic wettability of the liquid within the heated pore (for stable conditions). It will also be used to visualize the evolution of the instabilities after they have been initiated. The coupling of an evaporator and condenser menisci in microgravity will be video recorded for the first time.

CHT HARDWARE CHARACTERISTICS

Experiment module (2)	11.6 by 5.5 by 6.6 cm, 3.5 kg
Base unit	11.3 by 8.1 by 3.1 cm, 1.9 kg
Display unit	9.4 by 6.8 by 6.6 cm, 2.1 kg
Control unit with cable	8.9 by 4.1 by 2.1 cm, 0.2 kg
Total weight (including cables, control unit, etc.)	12.7 kg
Nominal power draw	12 W
Test fluid	Ethanol
Data acquisition	Spacelab camcorder, color video camera, thermocouples (12), pressure transducer

ABOUT THE GLOVEBOX

The Glovebox (GBX) is a multiuser facility developed for conducting experiments on Spacelab or in the shuttle middeck. It has been designed to accommodate biological, fluids, combustion, and materials science experiments. It can contain powders, splinters, liquids, or bioparticles that could result from such operations, whether accidentally or purposefully. Thus a shuttle crew member can carry out operations involving small quantities of toxic, irritating, or potentially infective materials that must not be allowed to contaminate the spacecraft atmosphere. CHT utilizes the GBX work area, power supply, and video capabilities.

The Glovebox was developed by Teledyne Brown Engineering (Huntsville, Alabama) and Bradford Engineering (the Netherlands) under contract to NASA Marshall Space Flight Center.

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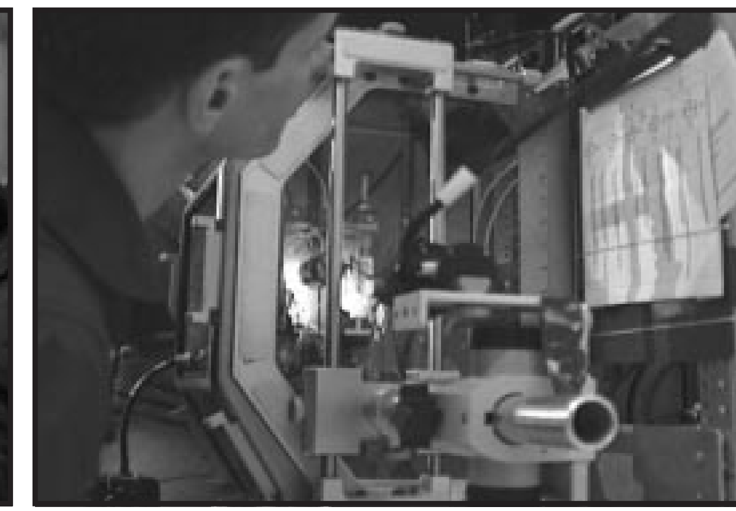
Capillary-Driven Heat Transfer (CHT) Investigation

MSL–1, STS–83

CHT training operations onboard the NASA Lewis Research Center DC–9 reduced-gravity aircraft.

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Microgravity Science and Applications Division

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